Universidade de Aveiro Departamento de Electrónica, Telecomunicações e Informática
2017

António Emanuel Teixeira Freire

Driver Personal Trainer – Aplicação móvel veicular de suporte a condutores.

Driver Personal Trainer – Onboard mobile application for supporting drivers

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Mestrado em Engenharia Informática, realizada sob a orientação científica do Doutor José Maria Amaral Fernandes, Professor Auxiliar do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e da Doutora Margarida Isabel Cabrita Marques Coelho, Professora auxiliar do Departamento de Engenharia Mecânica da Universidade de Aveiro

I dedicate this text to my father, he is the one that teach me to never give up, even when all the odds are not in my favour.

o júri

presidente

Prof. Doutor Carlos Manuel Azevedo Costa
professor auxiliar do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro

Prof. Doutor Miguel Tavares Coimbra
professor auxiliar da Faculdade de Ciências da Universidade do Porto

Prof. Doutor José Maria Amaral Fernandes
professor auxiliar do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro

Agradecimentos / acknowledgments

First, I would like to give my gratitude to my supervisor, Professor Doctor José Maria Fernandes for his advices and for the opportunity to develop a Master dissertation in my area of interest.

Finally, I would like to thanks to my family, friends and colleagues for all of their interest and support.

palavras-chave

Monitorização, condução eficiente, assistência de condução, ELM327, OBD2, vitaljacket, android, smartphone, fuel trim.

resumo

Nos dias de hoje os veículos de combustão estão a se tornar cada vez mais eficientes para o tamanho do seu motor, produzindo mais potência e menos emissões nocivas em utilização por capacidade de motor. Infelizmente, o consumo de combustível é muito sensível à forma como os condutores conduzem os veículos, sendo facilmente afetado por más decisões de condução.

Nesta dissertação apresentamos o DPT (Driver Personal Trainer), um assistente móvel que providencia feedback em tempo real baseado num indicador de eficiência. O DPT recolhe informação da centralina (ECU) e comportamento do veiculo, juntamente com dados fisiológicos do condutor. Depois de recolhida, esta informação pode ser analisada utilizado uma ferramenta de analise desenvolvida para o efeito, de modo a compreender melhor as reações do condutor em diferentes cenários.

Utilizando o assistente do DPT, o condutor pode ajustar o seu estilo de condução com base no feedback providenciado pelo assistente de modo a ter uma condução mais eficiente.

keywords

Online monitoring, driving efficiency, driving assistance, ELM327, OBD2, vitaljacket, android, smartphone, fuel trim.

abstract

Nowadays the vehicle's combustion engines are becoming more and more efficient for their size, producing more horsepower and less exhaust emissions per liter capacity. Unfortunately, the fuel consumption is very sensitive to the way the driver drives the vehicle, being easily affected by some bad driving decisions.

In this dissertation we present the DPT (Driver Personal Trainer), a mobile assistant that can provide real-time feedback to the driver based on a direct indicator of efficiency. The DPT collects online information from vehicle ECU, dynamics and driver physiology. Later this information can be analysed using a developed offline analyser tool with the goal to understand the driver actions in different scenarios.

Using the DPT assistant, the driver can adjust its driving style according to the indicator feedback resulting in a more efficient driving.

Contents

List of Figures

List of Tables

List of Acronyms

CAN bus ....Controller Area Network

CSV ....Comma-separated values

DTW ....Dynamic Time Warp

DPT.......................Driver Personal Trainer

DPT-OA ....Driver Personal Trainer Offline Analyser

EBC ....Electronic Braking System

ECG .... Electrocardiography.

ECU .... Engine Control Unit.

ENMC.................. Entidade Nacional para o Mercado de Combustíveis.

GLONASS............Global Navigation Satellite System.

GPS....................... Global Position System.

HR......................... Heart Rate

MAF .... Mass air-flow

MAP .... Manifold absolute pressure

MIROAD..............Mobile-Sensor-Platform for Intelligent Recognition Of Aggressive Driving

OBD......................On-Board Diagnostic

OBD2....................On-Board Diagnostic version 2

PID........................Parameters IDs

RPM......................Rotations per minute

SDK ....Software Development Kit

UI ....User Interface

VSS.......................Vehicle Speed Sensor

1 Introduction

1.1 Motivation and context

Nowadays the vehicle's combustion engines are becoming more and more efficient for their size, producing more horsepower and less exhaust emissions per liter capacity. Unfortunately, the fuel consumption is very sensitive to the way the driver drives the vehicle, being easily affected by some bad driving decisions. The driving style of a driver can sometimes be aggressive, especially in heavy traffic situations, in those cases the heartrate increases, this can lead to sudden steering wheel movements, unnecessary hard braking and more throttle than needed, resulting in more fuel consumption and more exhaust emissions from the vehicle.

Air pollutant emissions from 1990 to 2014 had reduced [1], especially with the introduction of the stricter Euro emission standards and fuel quality standards. Nether less, the air pollution is a major concern in modern society, it can lead in advance appearance of some diseases and even in the increases of mortality rate if subjects are exposed to it in a continued way. According to a study published in 2004 [2], the long-term exposure to air pollution for subjects with residence near a major road can increase its mortality rate by 2.5 years, chronic pulmonary disease by 3.4 years, chronic ischemic heart disease by 4.4 years and diabetes for 4.4 years.

According to ENMC (National entity for the fuel market) data [3] in the last two years (2015-2017) the fuel prices did not varied much, but in every fuel price increase there is a negative impact in the profit of companies that use fuel in its business (e.g. transport company's). Even in a family that uses a car in a daily basis every fuel increase has a negative impact in the family budget, so if fuel consumption is dropped, it always has a good impact in company's profit or in family's budget's.

Driving in fatigued conditions is dangerous and can be compared with driving in drunk conditions in terms of driver attention. According to some study's [4] , around 20% of all road accidents are fatigue related, knowing this, some car manufactures already develop some systems to detect when the driver is becoming drowsy. This in-car systems can use steering wheel pattern movements, driver eye/face monitoring and physiological measurement like HR signal [5].

1.2 Objectives

The high-level objective of this work is to provide a technical solution that help characterize how the driver perform while driving with the goal to help them drive in a safer and conservative way. Our ulterior objective, outside of the scope of this work, is to use our system to better understand driver's behaviours in different scenarios namely finding driving characteristics to take into account to provide better advice the driver while driving.

Our main result is the DPT (Driver Personal Trainer), a mobile assistant that can provide real-time feedback to the driver based on a direct indicator of efficiency (Fuel Trim). The DPT is able to online collect information from vehicle ECU (Engine Control Unit) (Throttle, Fuel Trim, Load, RPM, etc), vehicle dynamics (GPS, Acceleration, Gravity, Rotation) and driver physiology (ECG, HR). All this information is collected and possible to review using a dashboard (DPT-OA), this matches the vehicle geographic position with the collected information and can be later used to identify markers and scenarios of efficient driving.

These markers and scenarios can be used to incorporate driver information and improve the feedback of the DPT in the future.

1.3 Dissertation Structure

This dissertation is divided into the following chapters, excluding this one.

- Chapter 2 – Related Work, this chapter presents some related works of our current work (DPT mobile solution). We give a brief explanation of the selected ones and compare them with the DPT mobile solution.
- Chapter 3 – Driver Personal Trainer, this chapter explains how the DPT was implemented, explaining its main objective, implemented architecture, implementation of the DPT-OA, collected data model and synchronization.
- Chapter 4 – Evaluation Trials and Results, in the chapter we explain the context in which the information was collected, how it was collected in the different trials and present a detailed analyse to the collected information in each trial.

- Chapter 5 – Conclusions and Future Work, in this chapter we present the thesis conclusion, what we have learned and some future work to be done.

2 Related Work

Assisting the driver while driving with the goal to adjust its driving style to a more efficient one is a subject of great interest, nowadays, many car manufactures spend more and more resources in developing more efficiently solutions for this matter. Driving in a more efficient way depends of many factors (road traffic, vehicle used, driver state, driver car interactions, etc), some systems take some factors in account other do not. In this chapter we will present some related works, giving special focus for the ones that use similar information with the information used in the DPT. In the end of the chapter we present a comparison between the selected similar works vs DPT.

2.1 Driving Coach

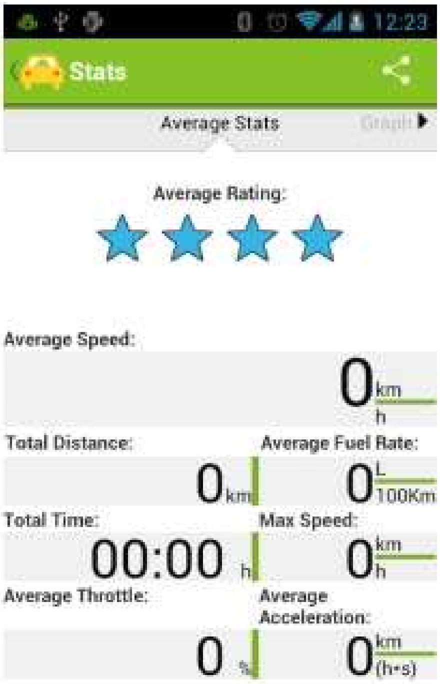

Figure 1 - Driving Coach UI (User interface)

Driving Coach [6] is a smartphone application developed in Faculdade de Engenharia da Universidade do Porto by Rui Araújo, Ângela Igreja, Ricardo de Castro and Rui Esteves Araújo. Its goal is to help drivers improve their driving behaviour, in a way to reduce the vehicle fuel consumption (driving more efficiently). The application reads the ECU signals from the OBD2 port using a Bluetooth device and with the help of a classification algorithm, gives evaluation feedback to the driver. Besides giving the evaluation feedback, the application displays some direct feedback metrics, fuel rate and acceleration (Figure 1).

To perform the data acquisition, the developers used a well-known android application called Torque Pro [7], the acquired dataset consists in six different metrics:

- Speed
- Acceleration
- Altitude
- Throttle percent
- Instant fuel consumption
- Engine rotations.

The application uses tree different classifiers, the first one for evaluation of the driving condition (urban, highway and combined), for this purpose, the vehicle velocity was used. A second one, uses the results of the first one, combined with the vehicle manufacture fuel consumption rates for each driving condition, and classifies the driving in a scale from 0 to 4 (visible stares classification in Figure 1). The last classifier is responsible for determine in real-time a useful driving tips to the driver with the goal to adjust its driving pattern behaviour in a more efficient one.

2.2 Artemisa

Figure 2 - Android Smartphone running Artemisa's Data Acquisition System

Artemisa [8] is an Android smartphone application that assists the driver in adopting a more fuel efficient driving style, it was developed in Universidad Carlos III by V.Corcoba Magaña and M. Muñoz-Organero.

Similar to Driving Coach [6], Artemisa uses a classification algorithm to classify and assist the driver while driving, the mobile solution is separated in two modules, the Artemisa's Data Acquisition System (Figure 2) and the Expert System. The Data acquisition system acquires the Fact Base that is used in the Expert System classification, it consists on the following metrics attributes:

- Speed (ECU)
- Acceleration
- RPM
- Current Gear
- Tire temperature
- Tire pressure
- Throttle position
- Brake position
- Fuel consumption
- Model (vehicle)
- Slope road
- Type road
- State road
- Weather conditions
- Location
- Speed (GPS)

The Expert System consists in four components (Figure 3):

- Preprocessing Module – Filters anomalous data and generates the information that is used in the classifier.
- Facts Base – Stores the information acquired in the acquisition system.

- Knowledge Base – Contains rules that define what is efficient driving, these are updated with the classifier results (initial rules are extracted from manuals about efficient driving).
- Classifier – Random Forest classification algorithm.

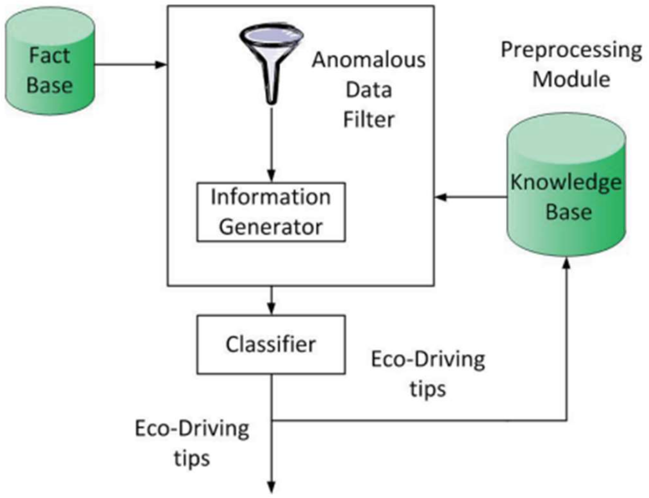

Figure 3 - Artemisa Expert System diagram

Using these four components, the Artemisa Expert System is able to give eco-driving tips to the driver while driving in response of current driver actions, based on past driving results.

2.3 MIROAD (Mobile-Sensor-Platform for Intelligent Recognition Of Aggressive Driving)

Figure 4 – MIROAD running on an iPhone 4 smartphone in a driving event [9].

MIROAD [9] is a mobile application (iPhone) that evaluates driving movements with the goal to detect aggressive driving movements. The application was developed in the University of California by Derick A. Johnson and Mohan M. Trivedi.

MIROAD uses the smartphone internal accelerometer, gyroscope and magnetometer (compass) sensors, GPS and back camera to detect, record and classify the vehicle movements. According to the research, the smartphone internal sensors can detect movement with similar quality to the vehicle CAN bus (Controller Area Network), making the MIROAD cheap, flexible and reliable in the quality of the acquired signal. The MIROAD uses a combination of the smartphone x-axis rotation rate, y-axis acceleration and pitch signals with the classical DTW algorithm to detect the vehicle movements events, the results were good, nearly 97% of the aggressive events were correctly identified.

2.4 Scania Driver Support – Onboard driver coaching

Scania driver support [10] is a real-time support system integrated in some Scania trucks (Figure 5), the system gives the driver hits and feedback with the goal of adjusting the driver driving style. The Scania Driver Support is designed for professional truck drivers and comes integrated as standard in every Scania vehicles that has an EBS (Electronic Braking System), range-splitter gearbox (12- or 12+2-speed, manual or with Scania Opticruise) and Scania Retarder.

Figure 5 - Scania Driver Support example displayed on a truck dashboard [11].

The Scania Driving Support gives different types of feedback to the driver. One of them is a score in percent for each category or a total score of all category's (Hill driving, Brake use, Anticipation and Choice of gears [12]), these feedback is continued displayed and it is based on the actions that the driver does in each category in the driving session (Figure 6).

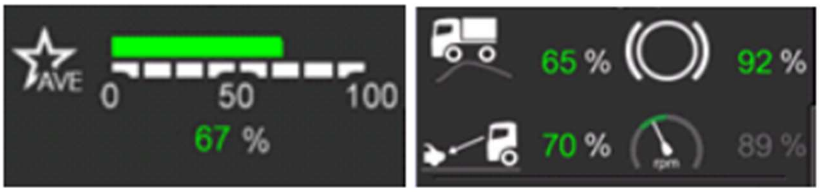

Figure 6 - Scania Driver Support - Percent feedback evaluation interface

Besides giving a score feedback, the Scania Driving Support gives hits combined with a star rating from 0 to 5 when one of the category's situation occurs (Figure 7).

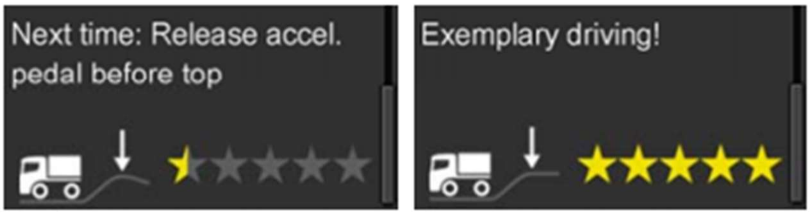

Figure 7 - Scania Driver Support - Driving tips with star rating feedback

Also, the Scania Driving Support gives gears recommendations when shifting manually (Figure 8).

Figure 8 - Scania Driver Support - Driving gear change warning

According to Scania [10] the usage of the driver support system showed improvements of 10% in fuel consumption and the fuel consumption variations were also dramatically reduced from 15-20% to 5%. Besides reducing fuel consumption, keeping the driver skilled over time reduces costs in vehicle maintenance, so, keeping the driver in a constant driving training in very attractive for vehicle fleet operators.

2.5 Comparison of solutions features

To compare the selected work's to the DPT, we selected some key aspects that we considered more relevant in this type of assistant systems (Table 1).

	Driving Coach	Artemisa	MIROAD	Scania Driver Support	DPT
Gives direct feedback	YES	NO	NO	YES	YES
Uses driver physiological information	NO	NO	NO	NO	YES
Uses environment information	NO	YES	YES	YES	YES
Uses vehicle information	YES	YES	NO	YES	YES
Stores the collected information	NO	YES	YES in 5 minutes segments	NO	YES
Collected information exportation	NO	NO	YES	NO	YES
Has an offline analyser	NO	NO	YES	NO	YES
Easy upgradable	YES	YES	YES	NO	YES
Easy changed from a vehicle to another (Portable)	YES	YES	YES	NO	YES

Table 1 -- Existent driver assistant systems comparison with the DPT mobile solution

We considered direct feedback to be, a direct (with no previous data processing) information of a collected value in real-time (no major delays). Besides the DPT, only the Driving Coach and the Scania Driver Support use it.

None of the selected work's uses driver physiological information. In similar engines, using the engine input information (different throttle percentage, current air temperature and pressure, etc) and some of the terrain information (uphill/downhill percentage) it is easy to predict the next behaviour of the engine. However, the driver reactions are different from driver to driver, or even in the same driver, depending of the driver state (if the driver is angry or distracted), the driving pattern will be different. Having some driver physiological input gives the DPT and advantage over the other assistant systems that do not use it.

Environment information, we considered to be the rotation and g-forces applied while driving, only the Driving Coach did not use any of this information. This information can give insight of the car behaviour, if it is braking, accelerating, cornering, uphill, downhill, etc.

ECU information is used in every of the selected systems except in the MIROAD that uses mostly the smartphone internal sensor to detect aggressive movements (the authors used ECU information, only to validate the solution).

Driving Coach uses data collected from another application, so, the application has no direct capability of storage data. The Artemisa stores collected data to later use it in the classification (Artemisa data acquisition system, figure 2). The MIROAD records all data in five minutes segments, if the recorded segment has no potentially-aggressive maneuver, the system automatically deletes it, this data can be used later for offline analyse in an application developed to view all the synced data. The Scania Driver Support is an integrated system in some Scania vehicles, we did not find and exact information relating this matter, so, we considered that it does not store any of the collected information, neither has data exportation or an offline analyser. Differently, the DPT stores all the collected information (synchronized and full data of each data source) for later analyse in an application developed for this effect.

Like Driving Coach, Artemisa and MIROAD, the DPT is a Smartphone application that can be easily upgradable (the DPT-OA can be easily updated to), being smartphone applications that uses external and portable sensors, this systems ca be easily migrated from one vehicle to another making them portable.

In overall, the DPT uses all the key aspects that we considered more relevant in this type of systems. This makes the DPT an assistant with great potential, that with some upgrades (in terms of information analyses) can be one of the best assistants around, considering that is low budget and offers good functionalities.

3 Driver Personal Trainer (DPT)

In this chapter we will present the details of the DPT. We will start by analysing the main objective, the available hardware and its restrictions, specifying the main requirements and discussing the approach taken for the implementation.

The DPT, is a mobile solution to assist the driver, the main objective is to collect information from vehicle and driver while driving and provide real-time feedback to the driver. The feedback is based on the collected information, these should be a direct indicator of efficiency – it may include warning messages for other types of information. The goal of the mobile solution is to help the driver adjust its driving style to a more efficient one.

3.1 Architecture

While driving, the driver can only interact with the car in a certain level, i.e. using the available controls, steering wheel, gearbox (in manual ones) and pedals. These interactions will result in new information in the current driving scenario, so, collecting it and analysing it, is of great importance to advice the driver according to a more efficient driving style. For that, we will use different sensors to collect information of different types, for a better understanding of the mobile solution, we design a diagram of the overall solution in Figure 9.

The driver interacts with the vehicle, resulting in new responses from the car ECU, the ECU information is being collected using the ELM327 that will transmit it via Bluetooth to the Android mobile phone running the DPT. The DPT will receive the HR signal from another external sensor (VitalJacket [13]) via Bluetooth. Additionally, the DPT collects GPS information and the other mobile internal sensors information's to get a better understanding of the current driving scenario.

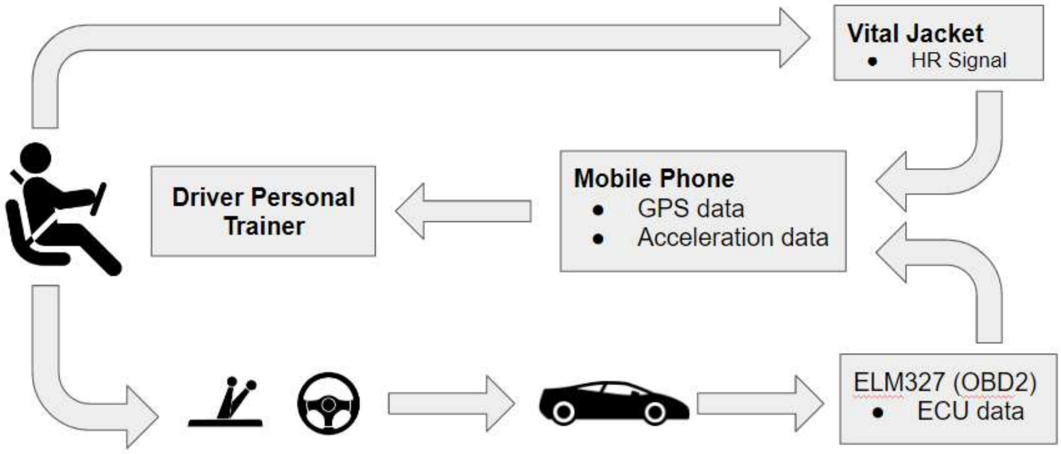

Figure 9 - Mobile solution architecture diagram

The data acquisition is done in real-time with all the sensors information synced the overall mobile solution works in a loop like system where the feedback is based on the instant information and context of the driving event.

3.2 The sensors

The different information collected by the system as origin in several sensors, some are internal of the mobile phone (or smartphone) and other are external devices connected via Bluetooth.

In DPT architecture we assumed a standard Android Smartphone for which the device used in the development is a good example: a Huawei Ascend P7 mini (Figure 10), running android 4.3 (Jelly Bean), capable of working with multiple Bluetooth devices with several embedded sensors namely Light, Linear Acceleration, Rotation, Gravity and GPS sensors. The internal GPS sensor has A-GPS and GLONASS making it more accurate and fast in getting a signal in built-up areas.

Figure 10 - Huawei Ascend P7 mini running DPT assistant

Figure 11 - VitalJacket wearable ECG from Biodevices

For monitoring the driver, our focus was on the heart rate (HR). Although there are several options, we relied on VitalJacket (Figure 11) available for the project. The VitalJacket is produced by Biodevices SA, it is a wearable vest that collects several vital signals from a person using electrodes placed in the person's body. It can store the collected information in an internal storage card or transmit it via Bluetooth to different devices (phones, laptops, etc), these characteristics makes it excellent for the current driving context i.e. the driver moves freely with the vest, since no wiring between the driver to the smartphone is needed, and the smartphone connection is facilitated using the VitalJacket android SDK.

Figure 12 - ELM 327

The collection of ECU information from the car relied on a device connected to the vehicle OBD2 port to scan for the ECU signals. We choose to use an ELM327 Bluetooth device (Figure 12), that, on request, reads the ECU available information and transmits it to the smartphone via Bluetooth. The used ELM327 is developed by Vgate [14] and it is a professional OBD scan tool, this has a more reliable processor unit than the traditional cheap OBD2 Bluetooth readers. To note that although several options exist on the market, their reliability may be an issue as in initial tests, using a cheaper ELM327 product we found limitations namely on the supported sampling rate from the ECU. The cheaper version did not support frequencies higher than 20Hz and presented unreliable connections even at slower rates. The current version did not present these issues.

3.2.1 Selected indicators

Not every OBD2 declared car metrics are always available, the availability depends on the car model - some manufactures bloke the access of some PID's via OBD2. For the selection of the car metrics to use we performed preliminary tests to assert which metrics were available via OBD2 in the car used (a ford fiesta mark 6 1.25i) in this work tests. The list of available sensors is present in table 2

Metric	Description
Distance Mil On	Distance travelled since engine start
Ignition Monitor	On/Off state of the ignition monitor system
Timing Advance	% in timing adjustment of the spark ignition cycle
Load	Engine load %
RPM	Engine rotations per minute
Throttle Position	Throttle %
Fuel Trim	% of fuel mixture adjustments -100 to 100% scale
Intake Manifold Pressure	Pressure applied in the intake manifold (used to power the brake system)
Air Intake Temperature	Temperature of the engine air
Speed	Vehicle speed in km

Table 2 – Available data from a ford fiesta mk6 1.25 ECU via OBD2

All available metrics were acquihired, but only the throttle, fuel trim were considered for analysis.

One of the decisions made was on the information used to characterize the driver behaviour/actions. For the driver actions information, we could use the acceleration and gravity to infer steering wheel movements and braking/throttle actions, but these values would imply further analysis namely to capture relevant patterns, therefore not directly usable. The only option that could be provide direct feedback was the throttle position i.e. the driver puts or lift the foot of the throttle. The minimum value recorded of the throttle position in all the route is 6.7% (not 0% like that should be expected when the driver haven't got the foot on the throttle), this value appears when the driver is not accelerating and the engine is working, because, for the engine to be kept working, the air intake butterfly valve must be slightly open, this valve is controlled by the throttle, so, since the throttle used is electronic (not cable throttle like old cars), the ECU keeps 6.7% of throttle when the driver is not pressing it.

For the fuel efficiency indicator one opinion was to use the fuel consumption rate from the ECU. Unfortunately, the used vehicle does not support this PID code via OBD2. According to B. Lightner [15] it is possible to calculate this value using MAF and the VSS data, unfortunately the used vehicle does not support the PID code for the MAF data, only for the MAP. It is still possible to calculate the MAF based on the MAP and some other data, but all this math can lead to some precision's errors and does not give us a direct insight of the unburned fuel, so we chose the fuel trim data for the fuel efficiency.

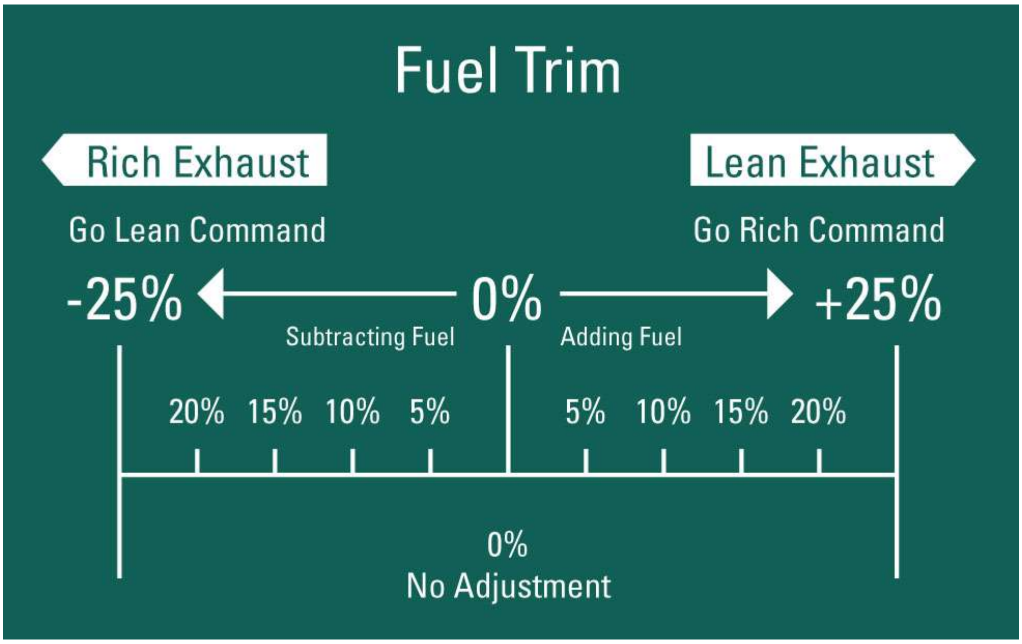

Figure 13 - Fuel Trim operation diagram [16]

The fuel trim (Figure 13) gives us the engine combustion efficiency, basically the fuel trim value is the percentage of the adjustment the ECU makes, in the quantity of fuel injected in the intake manifold to maintain the ideal air-fuel mixture for a complete combustion (i.e. 14.7 parts of air per one part of fuel). If the fuel trim value is 0%, this means that the combustion has exactly enough air to burn all the fuel, if the fuel trim is below 0% the engine has not enough air to burn all the fuel, resulting in unburned fuel and more bad emissions, if the fuel trim is over 0% the engine has more air than needed to burn the injected fuel, resulting in less bad exhaust emissions.

3.3 *DPT assistant*

The DPT assistant is the main visible application interface of the DPT Android application. It is responsible for collecting the information (both driver and car) and to present feedback to the driver.

The DPT assistant application provides two different modes, one providing raw reading from the data sources, the other diving driver assistance. These modes can be commuted by using a single swipe.

3.3.1 Raw data collection UI

The "Raw data" interface (Figure 14), contains a configuration section with some indicators of the externals data sources status, an activation section to activate the desire data sources for recording, including some configurations buttons for connecting the external Bluetooth devices (ELM327 and VitalJacket) and a button to start/stop the recording. When a data source is activated, a new section showing its available data types becomes visible, but the respective data is only displayed when the recording is started.

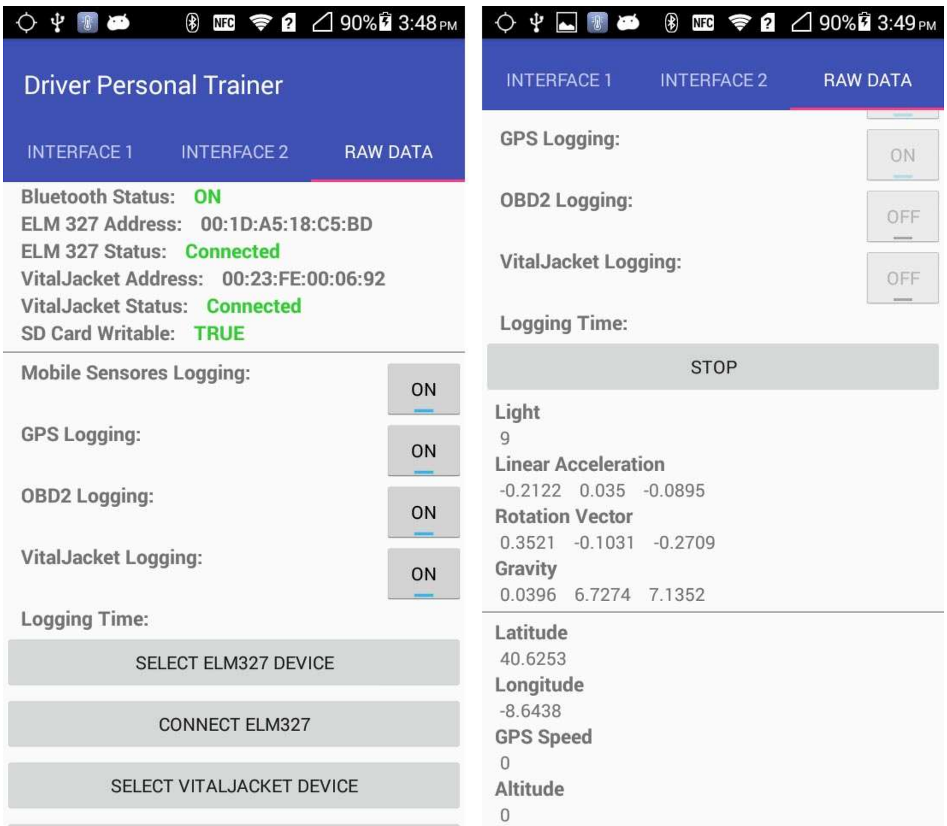

Figure 14 - DPT Raw data interface

3.3.2 Assistant UI

The DPT assistant (Figure 15), has two similar screen, they only differ in the type of data displayed. Both provide a gauge indicator to give direct feedback to the driver (the actual metric used it Fuel Trim, the selection is better described in data analyse section). The line chart in the bottom presents an historic view of the last 20 seconds of changes in the gauge values. This, helps the driver control the effects of its driving reactions based on the indicator historic results. The selection of a car gauge analogue gauge was made as it is familiar to most drivers. It provides the main driving metric output. In the top, the warning messages are presented whenever a predefined event occurs (the message is displayed for 1 second). These interfaces only work if the DPT is collecting data.

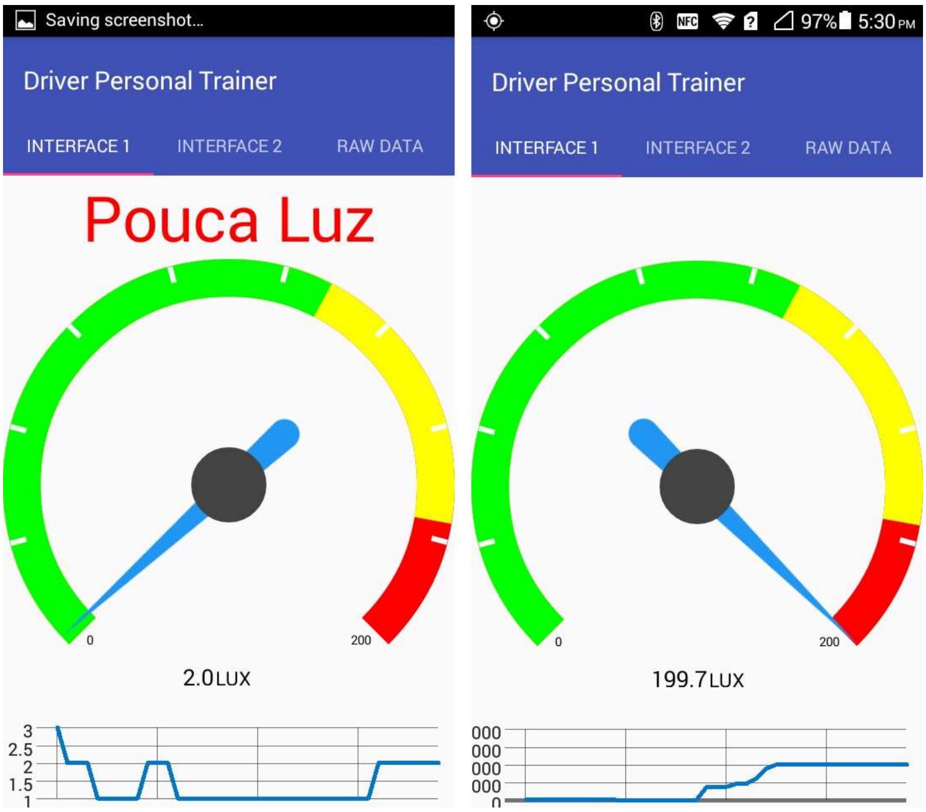

Figure 15 - DPT main UI (Light indicator)

3.3.3 Warning messages and selected indicator

Based on the data analyse we did so far, the warning messages that we can give to the driver will be more related to the travelled route, in a way to anticipate what comes ahead, (e.g.

warning that an intersection is near) so that the driver ca keep the throttle more normalized and the HR lower.

We defined some messages for testing purpose in the early selected route, the messages will be:

- “Calm down” when the HR is greater than 160 bpm.
- “Intersection” when the driver is near an intersection (defined fixed intersections for the early selected route)
- “Roundabout” when the driver is near a roundabout.

Since this is for testing purpose of proof of concept only, only static intersections for the first section will be analysed (Shopping centre car park entry and gas station entry) but more will be defined in the DPT mobile application.

For the interface indicator, the Fuel Trim will be the selected one, with a modified gauge (Figure 16).

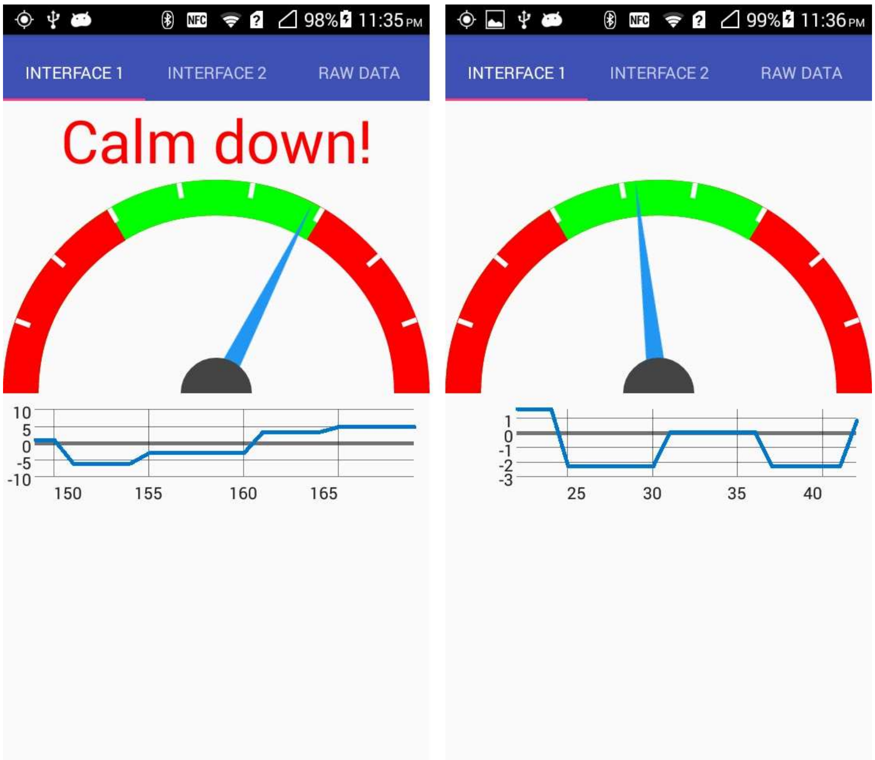

Figure 16 - DPT main UI (Fuel Trim indicator)

3.4 DPT- Offline analyser (DTP-OA) and collected data

A web application was developed specially for this type of data analyse (DPT offline analyser DPT-OA). It provides an option to display all data collected from DPT in the global log “Global_Log.csv” file. By default, when imported from the mobile, this file is placed in the data folder of the DPT-OA (Figure 17). As the information is synchronized, it is possible to use the DPT-OA to relate the several measures with the actual driver route in the map. The metrics can be extracted/reviewed for the entire driving section or for specific intervals selected over the map using flag icons as markers (i.e. start and end). To create a small trip, we just press the desired points/locations in the line chart (viewing the corresponding location in the map while mouse over the chart) and a new section on the right will appear with statistics for the selected small trip (between the flags in the map).

The graph support zooming on specific sections by just selecting the section in the graph with the mouse (Figure 18).

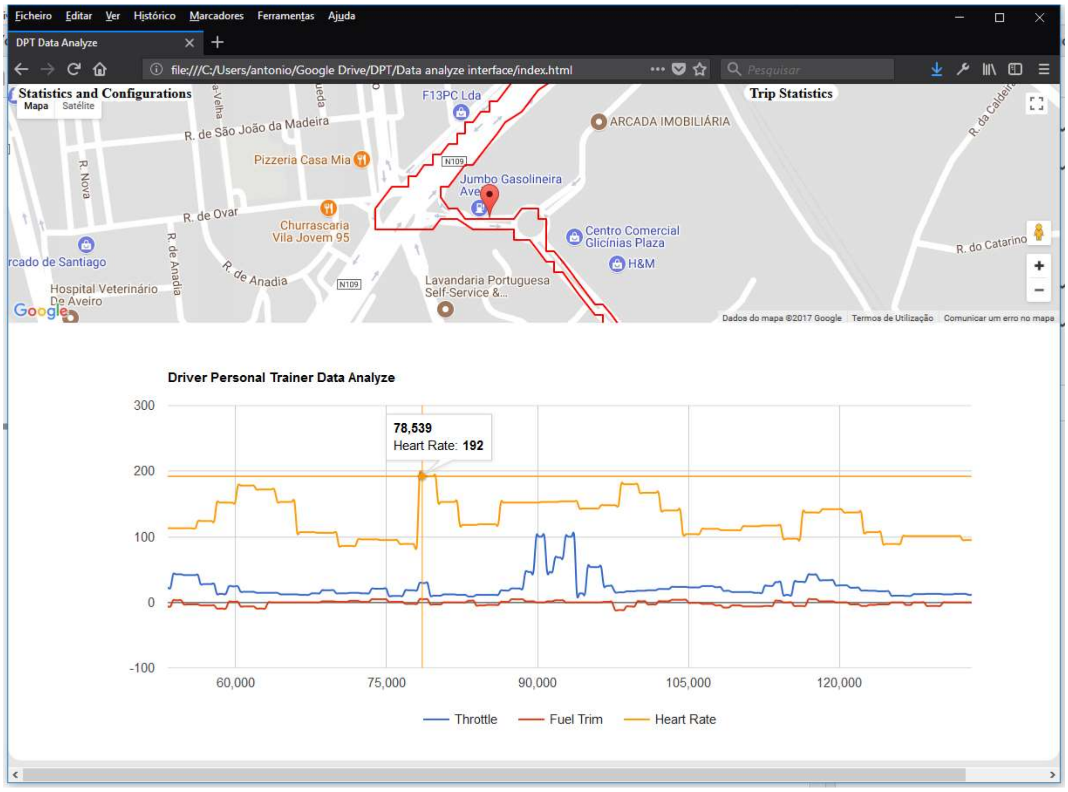

Figure 17 - DPT Offline Assistant (DPT-OA) - Using zooming support to analyse data in a specific section to relate fuel trim with throttle and HR

The DPT-AO also provides exporting capabilities in CSV format for the complete session or for the route segmentation section.

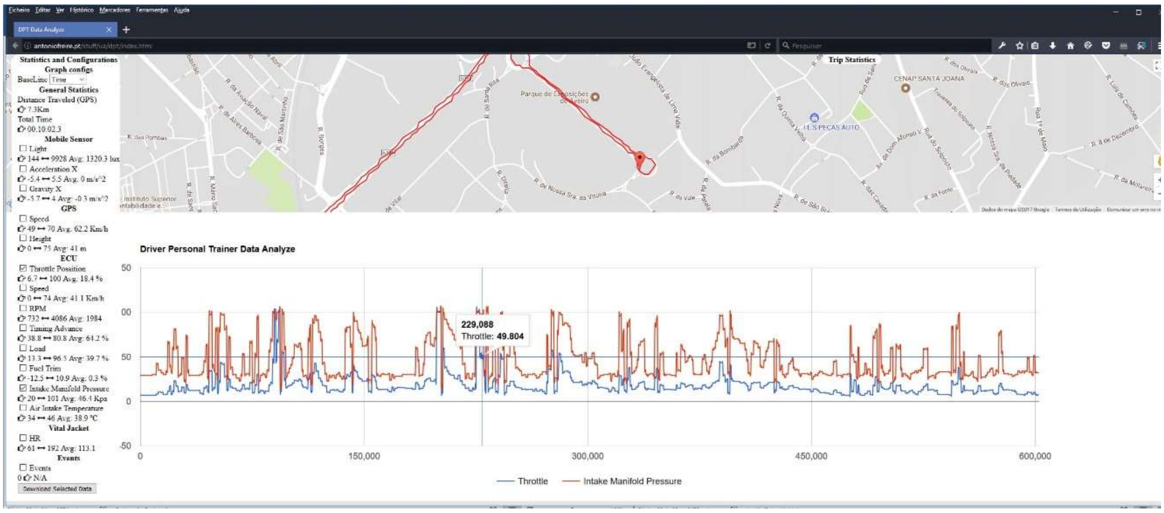

Figure 18- DPT-Offline Analyser (DPT-OA).: it allows selecting indicators (left) and review their evolution along time (bottom graph) and is space (top map)

3.5 Implementation details

For the implementation of the mobile solution we developed a mobile Android application (DPT) to monitor and assist the driver while driving, and a web application (DPT-OA) to analyse offline the data of each driving event. To transfer the data from the DPT to the DPT-OA, we used CSV files, for the DPT-OA to use these files, they have do use a pre-defined model described in the Data Model (3.6.1), only the synced one, that contains all the acquired data (Global_Log.csv) is used in the DPT-OA.

3.5.1 Data model

Prior the actual implementation of the DPT system the first stage was to identify the data sources and define the data model and organization.

One important option was to use a folder based data organization and adopt CSB as based data format. For each data collection, a new folder is created in witch its name is the date and the time of the recording in the format YYYY-MM-DD_HH-MM-SS. We store the acquired information in different CSV files, each is related to a specific data source, in more detail:

- “Global_Log.csv”, contains all the acquired data synchronized.

- Location_Log.csv containing GPS information collected from the smartphone;
- OBD2_Log.csv for ECU information;
- Sensor_Log.csv for mobile sensor information;
- VitalJacket_Log.csv for VitalJacket information and a ECG file for each ECG signal received from the VitalJacket).

The content of the CSV files are organized in tables, in more detail, each CSV file contains:

Location_Log.csv:

1. TimeStamp (ms)
2. TimeStamp (UTC)
3. Latitude
4. Longitude
5. GPS Speed (km/h)
6. Height (m)

Sensor_Log.csv:

1. TimeStamp (ms)
2. TimeStamp (UTC)
3. Light (Lux)
4. Linear Acceleration X (m/s^2)
5. Linear Acceleration Y (m/s^2)
6. Linear Acceleration Z (m/s^2)
7. Rotation Vector X (m/s^2)
8. Rotation Vector Y (m/s^2)
9. Rotation Vector Z (m/s^2)
10. Gravity X (m/s^2)
11. Gravity Y (m/s^2)
12. Gravity Z (m/s^2)

OBD2_Log.csv:

1. TimeStamp (ms)
2. TimeStamp (UTC)
3. Distance MilOn (km)

4. DTC Number
5. Ignition Monitor (On/Off)
6. Timing Advance (%)
7. Load (%)
8. RPM (rpm)
9. Throttle Position (%)
10. Fuel Trim (%)
11. Intake Manifold Pressure (Kpa)
12. Air Intake Temperature (ºc)
13. Speed (km/h)

VitalJacket_Log.csv:

1. TimeStamp (ms)
2. TimeStamp (UTC)
3. Battery level (%)
4. HR (bpm)

ECG-“timestamp”:

1. TimeStamp (ms)
2. TimeStamp (UTC)
3. ECG.

Global_Log.csv:

1. TimeStamp (ms)
2. TimeStamp (UTC)
3. Light (Lux)
4. Linear Acceleration X (m/s^2)
5. Linear Acceleration Y (m/s^2)
6. Linear Acceleration Z (m/s^2)
7. Rotation Vector X (m/s^2)
8. Rotation Vector Y (m/s^2)
9. Rotation Vector Z (m/s^2)
10. Gravity X (m/s^2)
11. Gravity Y (m/s^2)

12. Gravity Z (m/s^2)
13. Latitude
14. Longitude
15. GPS Speed (km/h)
16. Height (m)
17. VJ Battery level (%)
18. HR (bpm).
19. Distance MilOn (km)
20. DTC Number
21. Ignition Monitor (On/Off)
22. Timing Advance (%)
23. Load (%)
24. RPM (rpm)
25. Throttle Position (%)
26. Fuel Trim (%)
27. Intake Manifold Pressure (Kpa)
28. Air Intake Temperature (ºc)
29. Speed (km/h)
30. Warning MSG

3.5.2 Obtaining data from ELM327

The ELM327 from Vgate, does not include an android SDK like biodevices provide for the use of the VitalJacket development. To use the ELM327 we used an external java library (obd-java-api [17]) developed by Paulo Pires. This java library has the ability to connect to different ELM327 devices versions and provides user friendly methods to translate the OBD2 PID's to formatted results.

3.5.3 Data Synchronization

In the DPT Android application, besides using the usual Android activity's and fragments classes for the in the development, in the aim of develop a better structed architecture we used separated Android background services for each data source acquisition. To help understand the synchronization and communication in the DPT we provide an activity diagram (Figure 19) with the fragment's, activity's and service's of the DPT Android application.

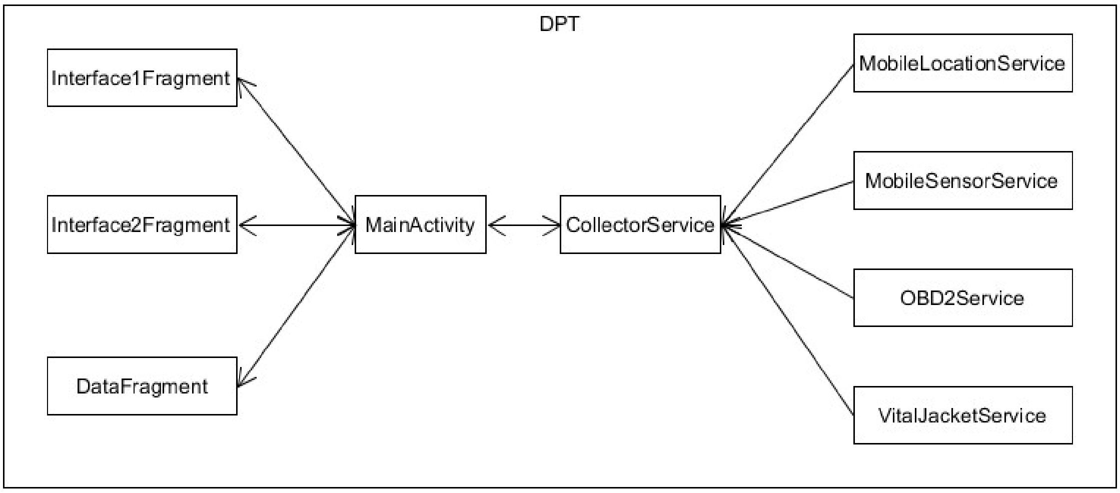

Figure 19- DPT activity diagram

Every service uses a developed class (LogCSVWriter.class) for writing csv files in the pre-defined model, the CollectorService writes the Global_Log.csv, MobileLocationService the Location_Log.csv, MobileSensorService the Sensor_Log.csv, OBD2Service the OBD2_Log.csv and VitalJacketService the VitalJacket_Log.csv.

Not all the data sources provide information in the same way, some are asynchronous and other are synchronous. The solution we chose to get the information synced, was to collect the current information of all the sensors in a given moment in the CollectorService, with this solution we stored the synced data in the Global_Log.csv at a rate of 4HZ (four samples per second). Each other service writes information at the maximum collected frame rate, for the OBD2Service we used a rate of 4HZ to avoid damaging the ELM327.

4 Evaluation - Trials and Results

In this chapter we start by presenting the acquisition context, describing where it was collected, the route and vehicle used characteristics.

Later we provide a detailed analyse in the collected data over the defined route, this was done using the DPT-OA with the goal to get some insight of the driver behaviours relatively to the route characteristics.

4.1 Data acquisition context

The DPT evaluation was performed in Aveiro, more precisely in a circular route of 7 km (Figure 20), starting and ending in the same point near Glicinias Plaza (a known shopping center in Aveiro). This route includes different traffic patterns, speed limits and some variations in topology i.e. some uphill/downhill/flat parts and roundabouts.

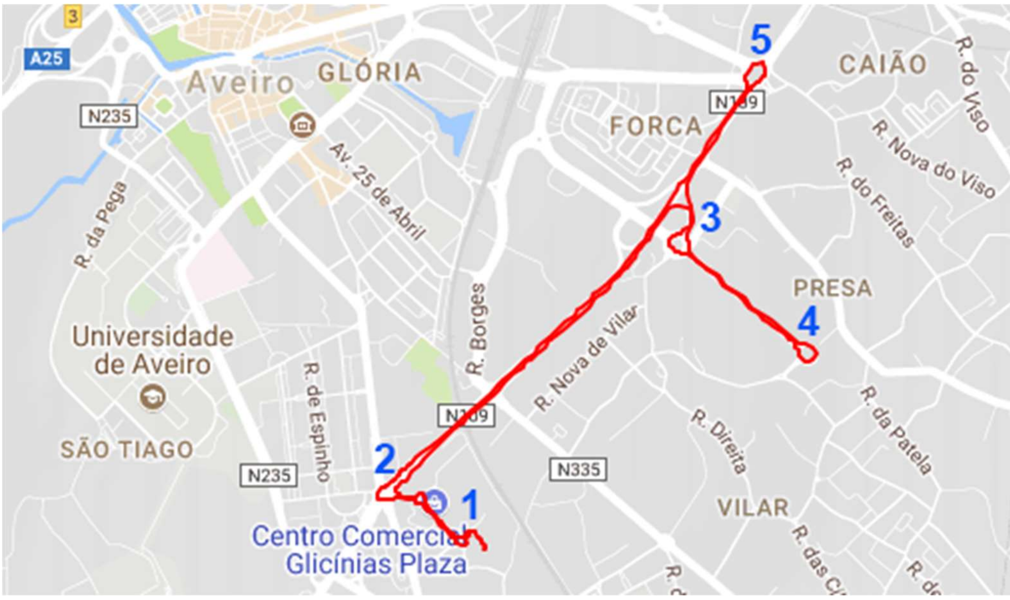

Figure 20 – Route using during trials: it comprises roundabout (1-5), traffic heavy (1-2) and low traffic (3-4),

To relate the collected data with the route different characteristics, we split it in different sections (A, B, C, D) between the roundabouts numbered in Figure 6.

- Section A: Between roundabout 1 and 2, this section is flat, with medium car traffic, has some traffic jams in holidays or in lunch time, since this is the access to the main shopping centre in Aveiro.

- Section B: Between roundabout 2 and 3, this section is mostly flat and straight with only one right corner in the end, has some uphill in the beginning, followed by a very small downhill (approximately 30 meters), flat surface and a downhill in the end corner. Car traffic flows easily most of the time since there are no stopping signals or intersections.
- Section C: Between roundabout 3 and 4, this section is like in and industrial area (no houses, only an events warehouse, periodically used). It has a straight road between the roundabouts, from roundabout 3 to 4 the road is uphill and from 4 to 3 downhill. Car traffic flows very easy since this part of the road has a high-speed limit (90km/h), no intersections and most of the time, the number of cars passing is minimum.
- Section D: Between roundabout 3 and 5, this section in the direction from 3 to 5, has an uphill part right after roundabout 3, until the main road that leads to the roundabout 5. The main road is flat, but the roundabout 5 has a high traffic, in fact, it's entries is where most traffic jams occur in Aveiro city.

Brand	Ford
Model	Fiesta Mark 6
Year	2005
Fuel type	Petrol
Power	75 hp/5500 rpm
Engine displacement	1252cm3 Naturally aspirated
Weight	1030 kg
Tyre size (used)	195/45 R16 84V
Tyre type (used)	Bridgetone Potenza RE050A
Tyre fuel consumption (used)	F (A-G scale, lower to higher)

Table 3- Used vehicle specifications [18]

The vehicle used is described in Table 3 and the driver is 30-year-old with 12 year of driving licence. Before starting collecting data, the driver must check the engine temperature, only if the engine is in the optimal temperature that the driver can start the data acquisition. Due some budget limitations, only one driver will be used and only one data acquisitions will be done in each trial.

4.2 Trials

We performed two trials:

- Trial 1 – Data collection, we collected data from (mobile sensor, GPS, vehicle ECU and VitalJacket) without any feedback to the driver of the assistance to the driver (we used raw data interface)
- Trial 2 – Data collection + feedback, we collected data as in trial 1, but provided feedback to the driver (warning messages and Fuel Trim as car analogue gauge).

4.2.1 Trial 1 – Data collection only

	Minimum	Medium	Maximum
Throttle	6,7 %	18,4 %	100 %
Fuel Trim	-12,5 %	0,3 %	10,9 %
HR	61 bpm	113 bpm	192 bpm

Table 4 – Route trial one, overall indicators statistics

In trial 1, the total distance was 7,3 km in a total of 10 minutes and 2 seconds. We measure (Table 4) an average 11,7 % (18,4 % - 6,7 %) of throttle which is a great value, the maximum was 100 %. The Fuel Trim average was 0,3% which is an excellent value, this means that the engine only did an average of 0,3% adjustments. Since it is a positive value, we can say that in the route, the engine intake mixture was a little lean, meaning that in average there was enough air to burn the fuel injected in the engine, resulting in les unburned fuel emissions i.e. less bad exhaust emissions. The HR was not bad for a subject of 30 years old, but there was a maximum of 192 bpm which is a very high value for the subject, later in the sections analyses we will try to get some insight of what happened to the other indicators when the maximum HR occurred.

Using the DPT-OA, we did a more detailed analyse in each section, first we started analysing the average values of each section, then, with the help of the DPT-OA we tried to get some context from the data.

4.2.1.1 Section A:

In this section we notice (Figure 21) an increase in the HR at 60000 ms and another increase at 78000 ms, both were in car intersections, the first was in the shopping centre car park entry and the second was in the gas station entry (maximum HR value in the section, table 5), so according to this observations, every time the driver came across intersections the HR increased, in the last observation, the HR increased very rapidly, where the driver had the reaction to take the foot from the throttle (minimum throttle value in the section) in 0.8 seconds (821ms). This could mean that the driver had to brake to avoid a possible crash or some similar situation. Another thing that we can view is that the Fuel Trim is directly related to the throttle, every time the driver gives more throttle, the combustion becomes rich (Fuel Trim > 0) and each time the driver eases up the throttle the combustion becomes lean resulting in more unburned fuel exhaust gases.

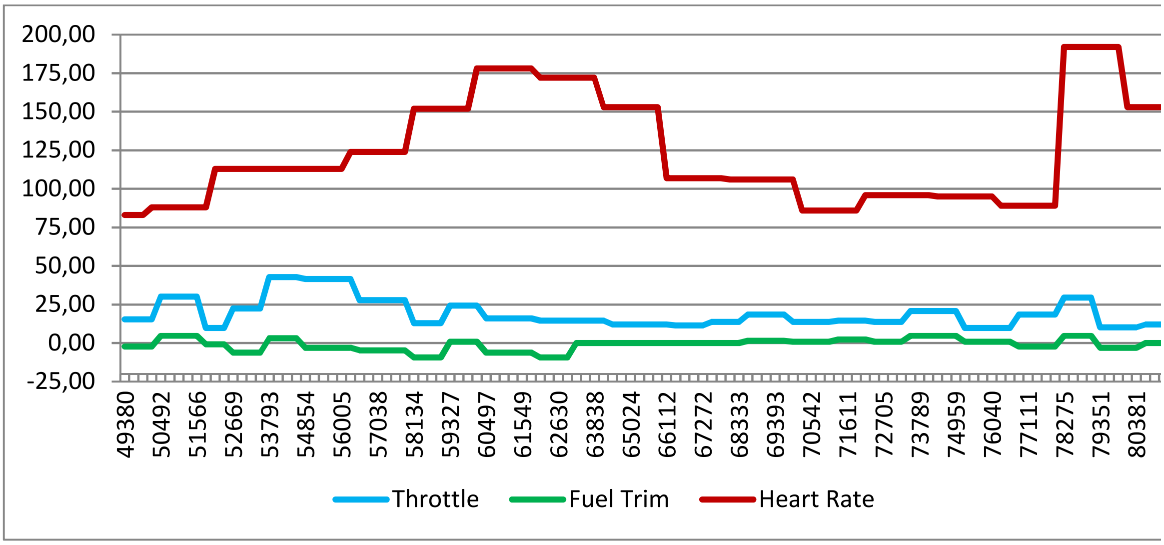

Figure 21 - Throttle, the fuel trim and the drive HR in Route trial one, section A:

	Minimum	Medium	Maximum
Throttle	9,8 %	19,1 %	42,7 %
Fuel Trim	-9,4 %	-0,9 %	4,7 %
HR	83	125 bpm	192 bpm

Table 5 - Summary (minimum, medium and maximum) of Throttle, Fuel Trim and the driver HR in the route of trial one, section A

4.2.1.2 *Section B:*

In this section we can view (Figure 22 and Table 6) similar results to what happened in section A (Figure 21 and Table 5), every time the driver is near an intersection the HR rises. Since this section is longer than section A, another thing that we can view with more data, is, that the longer the HR stays high, the less linear the throttle actions are. As a result, the fuel trim alters more from zero than when the HR is lower, resulting in more fuel injection or in more unburned fuel exhaust gases. With this observation we can assume that the longer the HR stays high, the less efficiency the driving becomes.

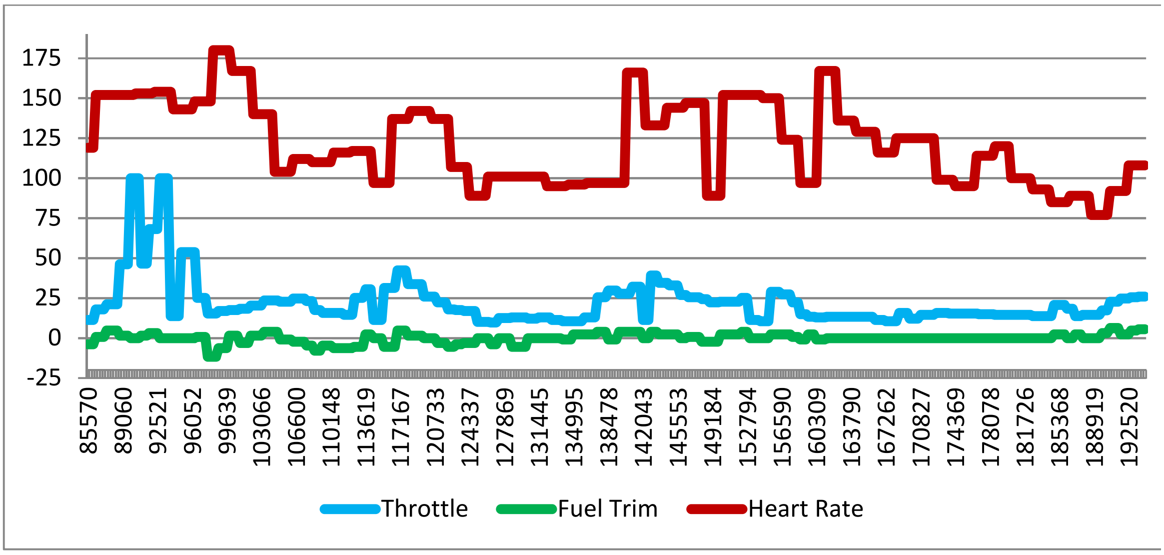

Figure 22 - Throttle, the fuel trim and the drive HR in Route trial one, section B

	Minimum	Medium	Maximum
Throttle	9,8 %	22,2 %	100 %
Fuel Trim	-11,7 %	0 %	6,3 %
HR	77 bpm	122 bpm	180 bpm

Table 6 - Summary (minimum, medium and maximum) of Throttle, Fuel Trim and the driver HR in the route trial one, section B indicators statistics

.

4.2.1.3 Section C:

In this section, the road is a straight-line with good visibility and very low car traffic. The only new observation (Figure 23 and Table 7) we found was that the HR increased a couple of meters before entering each roundabout, inside the roundabouts the HR was low. The assumption that we make based on the observation, is that the HR increases when a roundabout is visible and there is no visibility to the other entries, as soon as the driver had visibility of the other entries car traffic, the HR decreased, and the throttle remain constant. One small observation is that with 100% throttle the fuel trim remain 0% (the driver did this in a straight-line, one in uphill another in downhill).

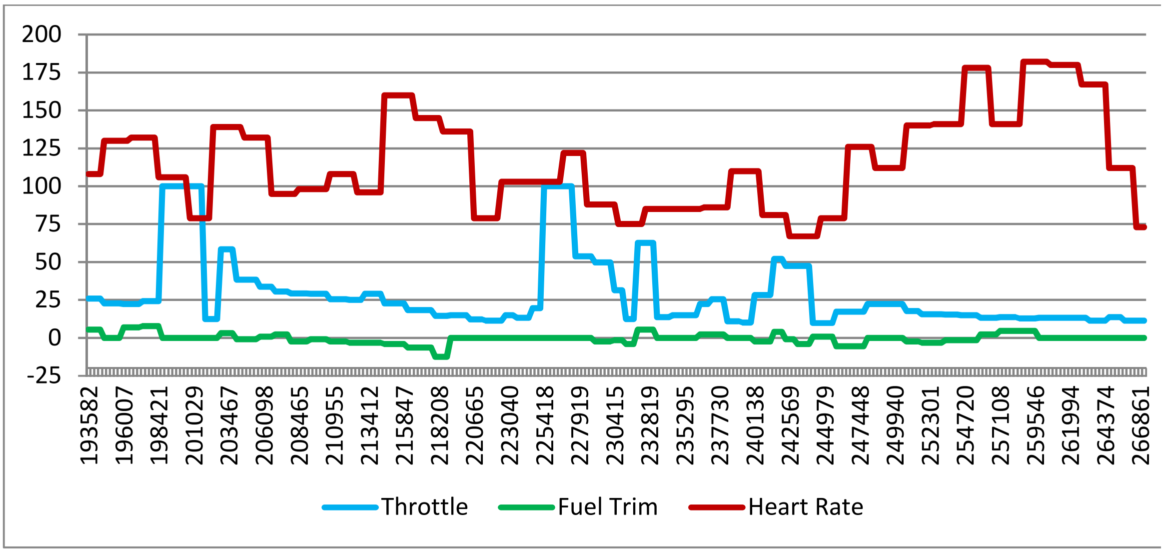

Figure 23 - Throttle, the fuel trim and the drive HR in Route trial one, section C

	Minimum	Medium	Maximum
Throttle	9,8 %	28,3 %	100 %
Fuel Trim	-12,5 %	-0,3 %	7,8 %
HR	67 bpm	116 bpm	182 bpm

Table 7 - Summary (minimum, medium and maximum) of Throttle, Fuel Trim and the driver HR in the route trial one, section C indicators statistics

4.2.1.4 *Section D:*

In this section we had the same observations (Figure 24 and Table 8) as in the other sections, the HR increases near intersection and decreases when visibility becomes clear. We can observe that this happened, for example, in the entry of the main road or the roundabout even with car traffic.

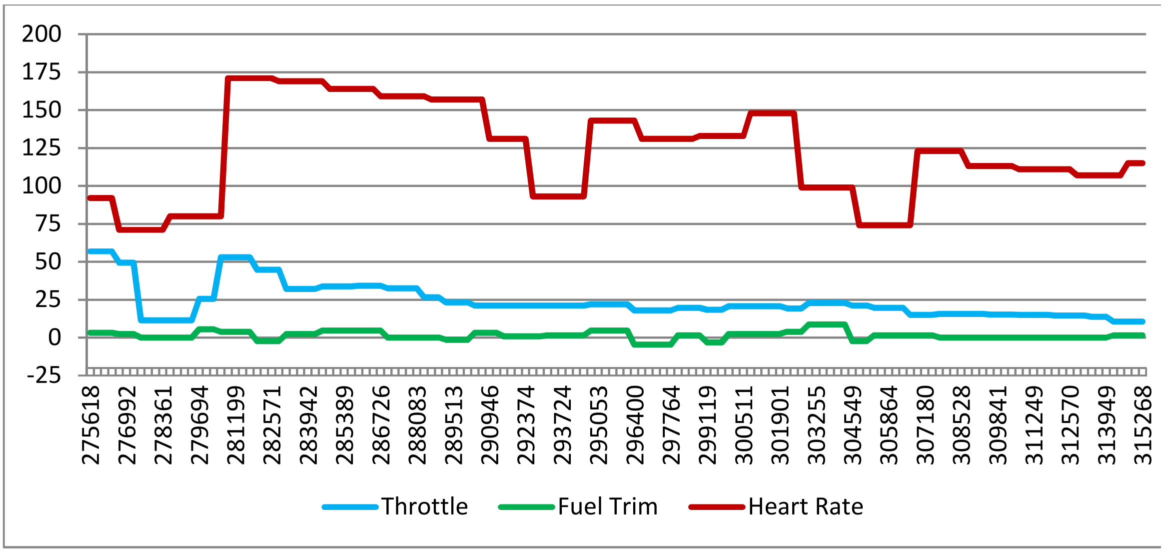

Figure 24 - Throttle, the fuel trim and the drive HR in Route trial one, section D

	Minimum	Medium	Maximum
Throttle	10,6 %	23,6 %	56.9 %
Fuel Trim	-4,7 %	1,5 %	8,6 %
HR	71 bpm	123 bpm	171 bpm

Table 8 - Summary (minimum, medium and maximum) of Throttle, Fuel Trim and the driver HR in the route trial one, section D indicators statistics

4.2.2 Trial 2 – Data collection and driver assistance

In the overall, we had (Table 9) a lower average throttle value and better maximum and minimum Fuel Trim than in the first trial. The HR value was lower, specially the maximum that was less than the average value of the first trial. These overall values differ between the two trials, this is most likely due the difference in car traffic conditions, in the first trial, the data was collected at 11:45, near lunch time, were many people usually came to the shopping centre to have lunch (i.e. more traffic in the selected route). In the second trial, the data was collected at 22:20, where car road traffic is low.

Using the DPT-OA, we did a more detailed analyse to the section A of the travelled route.

	Minimum	Medium	Maximum
Throttle	-7,8 %	20,2 %	100 %
Fuel Trim	-8,6 %	0 %	8,6 %
HR	75 bpm	92 bpm	103 bpm

Table 9 - Summary (minimum, medium and maximum) of Throttle, Fuel Trim and the driver HR in the route trial two, overall indicators statistics

4.2.2.1 Section A:

In this section, the DPT app showed and recorded the defined warnings relating to the intersections (value 10 in the events), but, the HR did not alter like in the first trial. With this observation (Figure 26 and Table 10) and the ones in the first stage (Figure 21 and Table 5) we will assume that the road traffic is the major influence in the HR incensement.

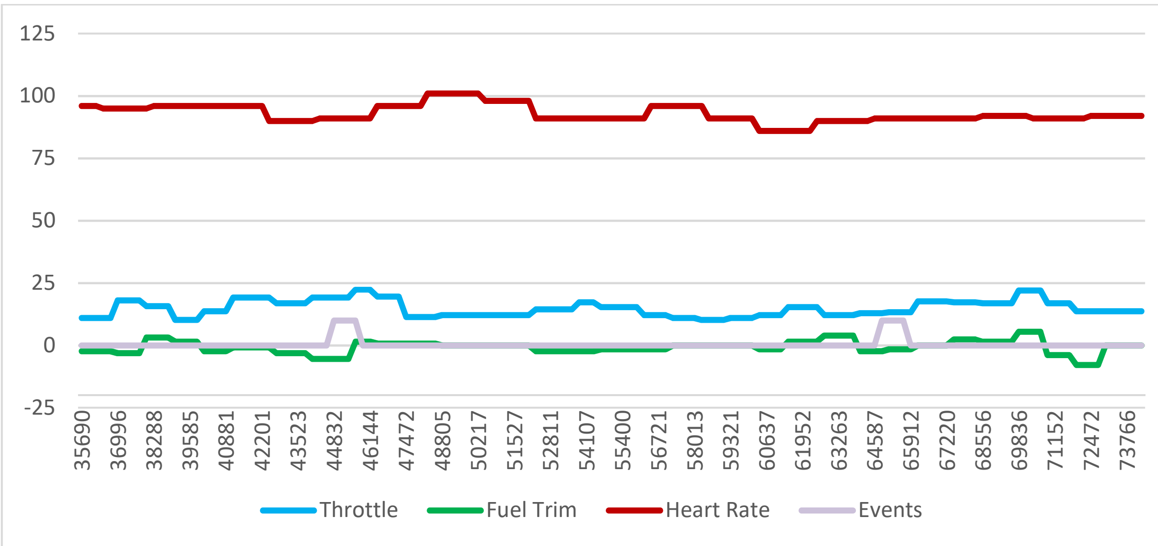

Figure 25 - Throttle, the fuel trim and the drive HR in Route trial two, section A

	Minimum	Medium	Maximum
Throttle	10,2 %	14,8 %	22,4 %
Fuel Trim	-7,8 %	-0,6 %	5,5 %
HR	86 bpm	93 bpm	101 bpm

Table 10 - Summary (minimum, medium and maximum) of Throttle, Fuel Trim and the driver HR in the route trial two, section A indicators statistics

4.3 Overall results

Based in the overall observations in both stages, we can establish that the HR can be a direct indicator of the road conditions, specially of car traffic. Based on the HR and throttle values we detected the driver physical reaction time in a possible emergency braking situation (trial one, section A).

Using Fuel Trim as an indicator in the DPT Assistant resulted in better Fuel Trim, maximum and minimum values. According to the driver, trying to keep the Fuel Trim gauge in the green section was not easy, but with practice probably the result will be better. A higher Fuel Trim minimum, results in less unburned fuel emissions, a lower maximum, results in lest wasted fuel in the combustion, in short, the engine efficiency was improved with the different driving actions from the driver.

5 Conclusions and Future Work

In this dissertation we presented the DPT system, it is composed by a mobile android application DPT for collecting online data of a driving event and an offline web application DPT-OA for offline analyse of the collected data. The DPT is installed in an Android smartphone, it collects data from the smartphone internal sensors and some affordable and easy to install external sensors (ELM327 and VitalJacket). These features make the DPT unique since it is a low budged and portable system that can be easy migrated from on vehicle to another.

Most of the drivers assistance system's that exists came embedded in the vehicles and cannot be migrated from one to another vehicle (for example, Scania Driver Support [10]). We analysed some systems that are not embedded in vehicles, but did not find any one that collects and uses driver physiological information (this is an advantage for the DPT vs the other ones that we analysed). There are some easy to migrate systems that are used to collect driver information with the goal to learn the driver habits i.e. some insurance boxes[19], this are used to evaluate the driver risk factor of having a possible car crash based on driving patterns. Unfortunately, these systems do no offer direct feedback to the driver, nor help the driver drive more efficiently.

The DPT helps drivers drive in a safer and conservative way, this can reduce fuel consumption and reduce fuel emissions per distance travelled. This benefit the environment and public health, especially in air polluted locations i.e. roads with major vehicle traffic. Reducing fuel consumption can also benefit family budgets that uses a vehicle in a daily basis or a company's profit that uses vehicles in its business by reducing the money spend in fuel.

The DPT assistant has an easy to view interface that uses a well-known car gauge like display for the direct feedback of the selected indicator (Fuel Trim), it has an historic line graph view of the last 20 seconds of the indicator values. According to the driver, this helped in adapting its actions to the indicator alterations. The warning messages gives the possibility to alert the driver of any possible panic situations or of road parts that require more attention of the driver i.e. intersections.

5.1 Future Work

The evaluation results of the DPT-OA presented in the dissertation gave some insight of the driving behaviours in different scenarios, however, a further validation is needed, given the limited number of drivers (only one), the reduced number of trials and the different road car traffic in the trials.

The main aim of this dissertation was on implementing (DPT) and validating (DPT-OA) a solution for a driving session that collects information from engine, car dynamics and physiological giving real-time feedback to the driver with the goal to improve the driving efficiency. The developed validation solution (DPT-OA) gave insight of the relation between driver physiology, actions in different road scenarios. The solution performed well, however, in the future, some updates can be made to gather more information types, and to give more assistance to the driver.

For future work, some of these updates could be made without any need of new hardware or sensors.

- Use the smartphone rear camera to detect road signs and give more assistance in braking, especially when the road sign is becoming closer and the driver is not stopping.
- Give different type of warnings based on the severity, including sound warnings for the most severe ones.
- Use the front camera with eye tracking to detect the level of attention on the road, giving the possibility to evaluate the level of distraction that the DPT can make to the driver, warnings in case of distraction, etc.
- Use the HR signal to detect the fatigue level of the driver.

Collecting information from driver could be useful in other scenarios, for example, for fleet management of delivery trucks. Reusing the developed DPT, DPT-OA and a web server, it is possible to develop a new solution that monitors a group of drivers, giving to the manager the power to know how are the most efficient drivers, putting those in longer trips and eventually saving in fuel costs.

6 References

[1] EEA, *Transitions towards a more sustainable mobility system*, no. 34. 2016.

[2] M. M. Finkelstein, M. Jerrett, and M. R. Sears, “Traffic air pollution and mortality rate advancement periods,” *Am. J. Epidemiol.*, vol. 160, no. 2, pp. 173–177, Jul. 2004.

[3] “ENMC - Evolução dos preços de referência e cotações internacionais.” [Online]. Available: http://www.enmc.pt/pt-PT/atividades/mercado-de-combustiveis/precos-de-referencia/evolucao-dos-precos-de-referencia/#gasolina;2. [Accessed: 22-Aug-2017].

[4] The Royal Society for the Prevention of Accidents (Institution), “Driver Fatigue and Road Accidents,” *Road Safety*, no. February 2001. 2014.

[5] G. Li and W.-Y. Chung, “Detection of Driver Drowsiness Using Wavelet Analysis of Heart Rate Variability and a Support Vector Machine Classifier,” *Sensors*, vol. 13, no. 12, pp. 16494–16511, Dec. 2013.

[6] R. Araujo, A. Igreja, R. de Castro, and R. E. Araujo, “Driving coach: A smartphone application to evaluate driving efficient patterns,” in *2012 IEEE Intelligent Vehicles Symposium*, 2012, pp. 1005–1010.

[7] Ian Hawkins, “Torque Pro (OBD2 / Carro) – Aplicações Android no Google Play.” [Online]. Available: https://play.google.com/store/apps/details?id=org.prowl.torque. [Accessed: 21-Nov-2017].

[8] V. Corcoba Magana and M. Munoz-Organero, “Artemisa: An eco-driving assistant for Android Os,” in *2011 IEEE International Conference on Consumer Electronics - Berlin (ICCE-Berlin)*, 2011, pp. 211–215.

[9] D. A. Johnson and M. M. Trivedi, “Driving style recognition using a smartphone as a sensor platform,” in *2011 14th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, 2011, pp. 1609–1615.

[10] “Scania Driver Support.” [Online]. Available: https://www.scania.com/group/en/wp-content/uploads/sites/2/2015/09/P09903EN-Scania-Driver-Support_tcm40-153879.pdf. [Accessed: 09-Jan-2017].

[11] "Scania Driver Support agora está disponível para linha de ônibus | Newsroom Scania Brasil." [Online]. Available: http://newsroom.scania.com/br/2014/01/13/tecnologia-scania-driver-support-agora-esta-disponivel-para-linha-de-onibus/. [Accessed: 21-Nov-2017].

[12] S. Group, "Scania Driver Support - Usage example." [Online]. Available: https://www.youtube.com/watch?v=vuVLnuDbtk8. [Accessed: 22-Nov-2017].

[13] "Vitaljacket Oficial Web Page." [Online]. Available: http://www.vitaljacket.com/?page_id=860&lang=pt-pt. [Accessed: 09-Jan-2017].

[14] "iCar - Vgate Technology.co,ltd Car automatic scanning diagnosis detection products." [Online]. Available: http://www.vgate.com.cn/en/. [Accessed: 11-Dec-2017].

[15] B. d Lightner, "AVR-Based Fuel Consumption Gauge," *Circuit Cellar*, no. 183, pp. 59–66, 2005.

[16] "Fuel trim can be a valuable diagnostic tool - Eastern Manufacturing." [Online]. Available: http://www.easterncatalytic.com/education/tech-tips/fuel-trim-can-be-a-valuable-diagnostic-tool/. [Accessed: 19-Oct-2017].

[17] "OBD-II Java API." [Online]. Available: https://github.com/pires/obd-java-api. [Accessed: 09-Jan-2017].

[18] "Auto-data Wiki Automotive Catalog." [Online]. Available: https://www.auto-data.net/en/?f=showCar&car_id=8036. [Accessed: 12-Oct-2017].

[19] "Ingenie BlackBox Insurance Company." [Online]. Available: https://www.ingenie.com. [Accessed: 08-Feb-2017].

7 Attachments

7.1 Location log

This file “Location_log.csv” (Figure 26) contains all the collected information from the smartphone internal GPS sensor in a driving session.

TIMESTAMP (MS)	TIMESTAMP	Latitude	Longitude	GPS Speed (km/h)	Height (m)
1,50642E+12	11:20:27	40.625378	-8.64372218	11.0	64.0
1,50642E+12	11:20:28	40.625355	-8.64369853	11.0	64.0
1,50642E+12	11:20:29	40.625334	-8.64367178	11.0	63.0
1,50642E+12	11:20:30	40.625307	-8.64364456	13.0	63.0
1,50642E+12	11:20:31	40.625282	-8.64360579	14.0	63.0
1,50642E+12	11:20:32	40.625277	-8.64355398	14.0	64.0
1,50642E+12	11:20:33	40.625273	-8.64350936	14.0	64.0
1,50642E+12	11:20:34	40.625276	-8.64346393	14.0	64.0
1,50642E+12	11:20:35	40.625283	-8.64343915	9.0	64.0
1,50642E+12	11:20:36	40.625285	-8.64342051	5.0	65.0
1,50642E+12	11:20:37	40.625288	-8.6434032	5.0	65.0
1,50642E+12	11:20:38	40.625291	-8.64338672	5.0	65.0
1,50642E+12	11:20:39	40.625307	-8.64335647	10.0	66.0
1,50642E+12	11:20:40	40.625319	-8.64332747	10.0	65.0
1,50642E+12	11:20:41	40.625340	-8.64329414	14.0	67.0
1,50642E+12	11:20:42	40.625362	-8.64325825	14.0	67.0
1,50642E+12	11:20:43	40.625385	-8.64325103	10.0	68.0
1,50642E+12	11:20:44	40.625406	-8.64322965	10.0	68.0
1,50642E+12	11:20:45	40.625416	-8.64323883	5.0	68.0
1,50642E+12	11:20:45	40.625359	-8.6438467	0.0	0.0
1,50642E+12	11:20:46	40.625428	-8.64324079	3.0	67.0
1,50642E+12	11:20:47	40.625437	-8.64324428	3.0	67.0
1,50642E+12	11:20:48	40.625437	-8.6432403	3.0	69.0
1,50642E+12	11:20:49	40.625449	-8.64325171	6.0	69.0

Figure 26 – Location_log.csv file content

7.2 OBD2 log

This file “OBD2_Log.csv” (Figure 27) contains all the collected information from the vehicle ECU in a driving session.

TIMESTAN	TIMESTAN	Distar	DTC Numb	Ignition M	Timing Ad	Load (%)	RPM (rpm	Throttle P	Fuel Trim	Intake Ma	Air Intake	Speed (Km/h)
1,51E+12	11:20:21	0	MIL is OFF	ON	56.07843	28.235294	933	8.627451	0.0	33	27.0	3
1,51E+12	11:20:22	0	MIL is OFF	ON	56.862743	28.62745	942	8.235294	1.5625	89	27.0	1
1,51E+12	11:20:23	0	MIL is OFF	ON	42.35294	42.35294	1515	36.862743	7.8125	78	27.0	3
1,51E+12	11:20:24	0	MIL is OFF	ON	61.960785	69.01961	1413	16.078432	3.125	66	27.0	10
1,51E+12	11:20:26	0	MIL is OFF	ON	78.039215	24.705883	1599	10.980392	1.5625	28	27.0	11
1,51E+12	11:20:27	0	MIL is OFF	ON	78.039215	22.745098	1587	11.372549	-2.34375	29	27.0	11
1,51E+12	11:20:28	0	MIL is OFF	ON	67.05882	24.705883	1554	12.156863	-1.5625	30	27.0	11
1,51E+12	11:20:29	0	MIL is OFF	ON	76.47059	32.156864	1685	14.90196	-1.5625	40	27.0	12
1,51E+12	11:20:30	0	MIL is OFF	ON	78.43137	25.882353	1897	13.725491	-1.5625	32	27.0	13
1,51E+12	11:20:31	0	MIL is OFF	ON	63.137257	38.82353	2189	16.862745	5.46875	43	27.0	15
1,51E+12	11:20:32	0	MIL is OFF	ON	47.45098	17.254902	1240	10.588235	3.90625	26	27.0	15
1,51E+12	11:20:33	0	MIL is OFF	ON	56.07843	22.352942	874	7.8431373	0.78125	29	27.0	14
1,51E+12	11:20:34	0	MIL is OFF	ON	54.117645	32.54902	806	8.235294	-1.5625	35	27.0	12
1,51E+12	11:20:35	0	MIL is OFF	ON	58.039215	28.62745	804	8.235294	-3.125	35	27.0	7
1,51E+12	11:20:36	0	MIL is OFF	ON	55.294117	28.62745	775	7.8431373	-4.6875	35	27.0	5
1,51E+12	11:20:37	0	MIL is OFF	ON	67.84314	55.294117	1730	16.862745	-0.78125	55	27.0	7
1,51E+12	11:20:38	0	MIL is OFF	ON	63.92157	63.92157	1523	18.431372	6.25	69	28.0	11
1,51E+12	11:20:39	0	MIL is OFF	ON	78.039215	26.27451	1750	13.725491	1.5625	32	28.0	12
1,51E+12	11:20:41	0	MIL is OFF	ON	72.54902	43.137257	2040	16.078432	3.90625	37	27.0	14
1,51E+12	11:20:42	0	MIL is OFF	ON	61.960785	18.431372	1501	11.372549	0.78125	26	27.0	12
1,51E+12	11:20:43	0	MIL is OFF	ON	60.39216	22.352942	887	8.627451	3.90625	32	27.0	9
1,51E+12	11:20:44	0	MIL is OFF	ON	57.2549	28.62745	767	8.235294	0.78125	35	27.0	7
1,51E+12	11:20:45	0	MIL is OFF	ON	52.941177	30.588236	782	8.235294	-0.78125	36	27.0	5
1,51E+12	11:20:46	0	MIL is OFF	ON	54.509804	30.19608	885	8.627451	-2.34375	36	28.0	4

Figure 27 - OBD2_Log.csv file content

7.3 Sensor log

This file "Sensor_Log.csv" (Figure 28) contains all the collected information from the smartphone internal sensors (Light, Linear Acceleration, Rotation and Gravity) in a driving session.

TIMESTAN	TIMESTAN	Light (lux)	Linear Acc	Linear Acc	Linear Acc	Rotation	Rotation	Rotation	Gravity X	Gravity Y (	Gravity Z (m/s^2)
1,51E+12	11:19:42	307.0	-0.001844	0.1634426	-0.112777	0.3709115	-0.107666	-0.249663	0.0588768	6.9870576	6.880984306335449
1,51E+12	11:19:42	307.0	-0.013746	-0.168260	-0.004137	0.3709115	-0.107666	-0.249663	0.0588768	6.9870576	6.880984306335449
1,51E+12	11:19:42	307.0	-0.013746	-0.168260	-0.004137	0.3643667	-0.102962	-0.247476	0.0588768	6.9870576	6.880984306335449
1,51E+12	11:19:42	307.0	-0.013746	-0.168260	-0.004137	0.3643667	-0.102962	-0.247476	0.0324500	6.8732876	6.9948015213012695
1,51E+12	11:19:42	284.0	-0.013746	-0.168260	-0.004137	0.3643667	-0.102962	-0.247476	0.0324500	6.8732876	6.9948015213012695
1,51E+12	11:19:42	286.0	-0.013746	-0.168260	-0.004137	0.3643667	-0.102962	-0.247476	0.0324500	6.8732876	6.9948015213012695
1,51E+12	11:19:42	286.0	0.2962633	-0.074011	-0.020338	0.3643667	-0.102962	-0.247476	0.0324500	6.8732876	6.9948015213012695
1,51E+12	11:19:42	286.0	0.2962633	-0.074011	-0.020338	0.3694480	-0.105949	-0.246934	0.0324500	6.8732876	6.9948015213012695
1,51E+12	11:19:42	286.0	0.2962633	-0.074011	-0.020338	0.3694480	-0.105949	-0.246934	0.1434945	6.9507536	6.916417121887207
1,51E+12	11:19:42	313.0	0.2962633	-0.074011	-0.020338	0.3694480	-0.105949	-0.246934	0.1434945	6.9507536	6.916417121887207
1,51E+12	11:19:42	313.0	0.2223447	-0.533236	0.0095577	0.3694480	-0.105949	-0.246934	0.1434945	6.9507536	6.916417121887207
1,51E+12	11:19:42	313.0	0.2223447	-0.533236	0.0095577	0.3485059	-0.117400	-0.239375	0.1434945	6.9507536	6.916417121887207
1,51E+12	11:19:43	313.0	0.2223447	-0.533236	0.0095577	0.3485059	-0.117400	-0.239375	0.5000123	6.6090240	7.2278056144714355
1,51E+12	11:19:43	339.0	0.2223447	-0.533236	0.0095577	0.3485059	-0.117400	-0.239375	0.5000123	6.6090240	7.2278056144714355
1,51E+12	11:19:43	339.0	0.1328486	-0.415274	0.7076086	0.3485059	-0.117400	-0.239375	0.5000123	6.6090240	7.2278056144714355
1,51E+12	11:19:43	339.0	0.1328486	-0.415274	0.7076086	0.3365923	-0.114672	-0.233434	0.5000123	6.6090240	7.2278056144714355
1,51E+12	11:19:43	339.0	0.1328486	-0.415274	0.7076086	0.3365923	-0.114672	-0.233434	0.5279009	6.3331308	7.468812465667725
1,51E+12	11:19:43	348.0	0.1328486	-0.415274	0.7076086	0.3365923	-0.114672	-0.233434	0.5279009	6.3331308	7.468812465667725
1,51E+12	11:19:43	336.0	0.1328486	-0.415274	0.7076086	0.3365923	-0.114672	-0.233434	0.5279009	6.3331308	7.468812465667725
1,51E+12	11:19:43	336.0	0.3418795	-0.182327	0.4197416	0.3365923	-0.114672	-0.233434	0.5279009	6.3331308	7.468812465667725
1,51E+12	11:19:43	336.0	0.3418795	-0.182327	0.4197416	0.3042445	-0.113920	-0.224022	0.5279009	6.3331308	7.468812465667725
1,51E+12	11:19:43	336.0	0.3418795	-0.182327	0.4197416	0.3042445	-0.113920	-0.224022	0.8041898	5.8927540	7.7973785400390625
1,51E+12	11:19:43	362.0	0.3418795	-0.182327	0.4197416	0.3042445	-0.113920	-0.224022	0.8041898	5.8927540	7.7973785400390625
1,51E+12	11:19:43	362.0	0.0052598	0.4711084	-0.126942	0.3042445	-0.113920	-0.224022	0.8041898	5.8927540	7.7973785400390625

Figure 28 - Sensor_Log.csv file content

7.4 VitalJacket log

This file "VitalJacket_Log.csv" (Figure 29) contains all the collected information from the vitaljacket used in the driver in a driving session.

TIMESTAM	TIMESTAM	BATTERY_	HR (bpm)
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119
1,51E+12	11:19:42	73	119

Figure 29 - VitalJacket_Log.csv

7.5 ECG signal information

This file “ECG-1506424782749.csv” (Figure 30) contains all the collected information from and ECG signal (500 samples per signal) from the VitalJacket used in the driver in a driving session.

TIMESTAM	TIMESTAM	ECG
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17
1,51E+12	11:19:42	-17

Figure 30 - ECG-1506424782749.csv file content

7.6 Global log

This file “Global_Log.csv” (Figure 31) contains all the collected information from the GPS sensor, other smartphone internal sensors (Light, Linear Acceleration, Rotation and Gravity), vitaljacket and ECU in a driving session. The information is all synchronized at a rate of 4 samples per second (4Hz).

TIMESTAN	TIMESTAN	Light (lux)	Linear Acc	Linear Acc	Linear Acc	Rotation \	Rotation \	Rotation \	Gravity X (	Gravity Y (	Gravity Z (	Latitude	Longitude	GPS Speed	Height (m	VJ BATTER	HR (bpm)	Distance I	DTC Numb	Ignition M	Timing Ad	Load	RPM	Throttle P	Fuel Trim	Intake Ma	Air Intake	Speed	Warning MSG
1,51E+12	11:20:36	239.0	0.0447	0.1651	0.1275	0.5504	-0.2961	-0.3385	0.4413	9.5535	2.1692	40.6253	-8.6435	64.0	14.0	72.0	163.0	0.0	MIL is OFF	ON	56.07843	22.352942	874	7.8431373	0.78125	29	27.0	14	N/A
1,51E+12	11:20:36	229.0	0.1895	0.0458	0.0916	0.5353	-0.3202	-0.3677	0.5222	9.5432	2.1965	40.6253	-8.6435	64.0	14.0	72.0	163.0	0.0	MIL is OFF	ON	56.07843	22.352942	874	7.8431373	0.78125	29	27.0	14	N/A
1,51E+12	11:20:36	232.0	-0.1479	0.0372	0.1514	0.5348	-0.3026	-0.3687	0.2717	9.5044	2.4006	40.6253	-8.6435	64.0	14.0	72.0	163.0	0.0	MIL is OFF	ON	56.07843	22.352942	874	7.8431373	0.78125	29	27.0	14	N/A
1,51E+12	11:20:36	228.0	-0.0278	-0.0588	-0.0316	0.5463	-0.2789	-0.3461	0.1757	9.4996	2.4284	40.6253	-8.6435	64.0	14.0	72.0	163.0	0.0	MIL is OFF	ON	54.117645	32.54902	806	8.235294	-1.5625	35	27.0	12	N/A
1,51E+12	11:20:37	288.0	-0.2617	0.1712	-0.5233	0.5709	-0.2511	-0.307	0.0309	9.5945	2.0285	40.6253	-8.6435	64.0	14.0	72.0	163.0	0.0	MIL is OFF	ON	54.117645	32.54902	806	8.235294	-1.5625	35	27.0	12	N/A
1,51E+12	11:20:37	287.0	-0.5325	-1.0838	-0.7506	0.5979	-0.2445	-0.2977	-0.1208	9.6708	1.6221	40.6253	-8.6434	64.0	9.0	72.0	163.0	0.0	MIL is OFF	ON	54.117645	32.54902	806	8.235294	-1.5625	35	27.0	12	N/A
1,51E+12	11:20:37	285.0	-0.0834	1.6482	0.4156	0.6093	-0.2629	-0.2954	-0.142	9.7555	0.9899	40.6253	-8.6434	64.0	9.0	72.0	163.0	0.0	MIL is OFF	ON	54.117645	32.54902	806	8.235294	-1.5625	35	27.0	12	N/A
1,51E+12	11:20:37	299.0	-0.4738	-0.8187	-0.4402	0.5832	-0.2639	-0.2927	0.2096	9.6566	1.6962	40.6253	-8.6434	64.0	9.0	72.0	163.0	0.0	MIL is OFF	ON	58.039215	28.62745	804	8.235294	-3.125	35	27.0	7	N/A
1,51E+12	11:20:38	297.0	-0.2913	0.1049	-0.2918	0.5947	-0.2622	-0.3027	-0.0797	9.685	1.5376	40.6253	-8.6434	65.0	5.0	72.0	165.0	0.0	MIL is OFF	ON	58.039215	28.62745	804	8.235294	-3.125	35	27.0	7	N/A
1,51E+12	11:20:38	296.0	-0.4964	0.2298	0.4913	0.6153	-0.2636	-0.3109	-0.2039	9.701	1.4213	40.6253	-8.6434	65.0	5.0	72.0	165.0	0.0	MIL is OFF	ON	58.039215	28.62745	804	8.235294	-3.125	35	27.0	7	N/A
1,51E+12	11:20:38	311.0	-0.1041	-0.2298	-0.6405	0.6254	-0.2361	-0.3109	-0.6838	9.7271	1.0427	40.6253	-8.6434	65.0	5.0	72.0	165.0	0.0	MIL is OFF	ON	58.039215	28.62745	804	8.235294	-3.125	35	27.0	7	N/A
1,51E+12	11:20:38	309.0	0.6902	-0.5398	-0.5326	0.6372	-0.2641	-0.3158	-0.5715	9.7784	0.4757	40.6253	-8.6434	65.0	5.0	72.0	165.0	0.0	MIL is OFF	ON	55.294117	28.62745	775	7.8431373	-4.6875	35	27.0	5	N/A
1,51E+12	11:20:39	310.0	0.494	1.6536	-1.2172	0.6355	-0.2958	-0.3176	-0.2534	9.8019	0.1712	40.6253	-8.6434	65.0	5.0	72.0	165.0	0.0	MIL is OFF	ON	55.294117	28.62745	775	7.8431373	-4.6875	35	27.0	5	N/A
1,51E+12	11:20:39	353.0	-0.3283	0.0291	-0.3804	0.6649	-0.3336	-0.3396	-0.6627	9.7282	-1.0455	40.6253	-8.6434	65.0	5.0	72.0	165.0	0.0	MIL is OFF	ON	55.294117	28.62745	775	7.8431373	-4.6875	35	27.0	5	N/A
1,51E+12	11:20:39	337.0	-0.3283	0.0291	-0.3804	0.6687	-0.3142	-0.3402	-0.8774	9.7257	-0.9009	40.6253	-8.6434	65.0	5.0	72.0	165.0	0.0	MIL is OFF	ON	55.294117	28.62745	775	7.8431373	-4.6875	35	27.0	5	N/A
1,51E+12	11:20:40	391.0	0.5178	-0.1449	0.2969	0.67	-0.2863	-0.3337	-1.202	9.6888	-0.9236	40.6253	-8.6434	65.0	5.0	72.0	144.0	0.0	MIL is OFF	ON	67.84314	55.294117	1730	16.862745	-0.78125	55	27.0	7	N/A
1,51E+12	11:20:40	398.0	-0.0815	-0.0112	0.7777	0.6596	-0.2559	-0.3204	-0.9829	9.7573	-0.0113	40.6253	-8.6434	65.0	5.0	72.0	144.0	0.0	MIL is OFF	ON	67.84314	55.294117	1730	16.862745	-0.78125	55	27.0	7	N/A
1,51E+12	11:20:40	416.0	0.5423	0.0409	0.3617	0.6466	-0.2461	-0.3086	-0.7633	9.7679	0.4188	40.6253	-8.6434	65.0	5.0	72.0	144.0	0.0	MIL is OFF	ON	67.84314	55.294117	1730	16.862745	-0.78125	55	27.0	7	N/A
1,51E+12	11:20:40	428.0	0.0057	-0.0792	0.2478	0.6422	-0.242	-0.3011	-0.6504	9.7684	0.5701	40.6253	-8.6434	65.0	5.0	72.0	144.0	0.0	MIL is OFF	ON	67.84314	55.294117	1730	16.862745	-0.78125	55	27.0	7	N/A
1,51E+12	11:20:41	434.0	0.2388	0.1237	0.1145	0.6363	-0.2321	-0.2896	-0.5357	9.7585	0.8097	40.6253	-8.6434	65.0	5.0	72.0	144.0	0.0	MIL is OFF	ON	67.84314	55.294117	1730	16.862745	-0.78125	55	27.0	7	N/A
1,51E+12	11:20:41	425.0	0.0633	-0.2545	0.085	0.6528	-0.2225	-0.2899	-0.8156	9.761	0.4769	40.6253	-8.6434	66.0	10.0	72.0	144.0	0.0	MIL is OFF	ON	63.92157	63.92157	1523	18.431372	6.25	69	28.0	11	N/A
1,51E+12	11:20:41	417.0	0.0117	0.2181	-0.1851	0.6464	-0.2298	-0.2862	-0.5997	9.7696	0.6044	40.6253	-8.6434	66.0	10.0	72.0	144.0	0.0	MIL is OFF	ON	63.92157	63.92157	1523	18.431372	6.25	69	28.0	11	N/A
1,51E+12	11:20:41	440.0	0.6441	-0.0243	0.0262	0.6613	-0.2014	-0.2768	-0.9531	9.7506	0.4343	40.6253	-8.6434	66.0	10.0	72.0	144.0	0.0	MIL is OFF	ON	63.92157	63.92157	1523	18.431372	6.25	69	28.0	11	N/A
1,51E+12	11:20:42	376.0	0.6441	-0.0243	0.0262	0.6586	-0.2123	-0.2719	-0.7275	9.7708	0.4155	40.6253	-8.6433	65.0	10.0	72.0	123.0	0.0	MIL is OFF	ON	63.92157	63.92157	1523	18.431372	6.25	69	28.0	11	N/A

Figure 31 - Global_Log.csv file content